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PRESSURE PULSATION MEASUREMENTS IN THE PIPE-LINES OF PISTON COMPRESSORS

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INTRODUCTION

The high speed piston compressors, both big and middle sizes, being actually in production result in their pipe-lines high amplitudes of pressure pulsation. The pulsation produces negative effect both on the compressor working conditions and on piping of compressed gas. Moreover, existence of pulsations in majority of cases causes indicated power increase and flow rate decrease. Besides of it pressure pulsation intensifies wearing and demages of compressors valves and also reduces the service life of crankshaft assembly. Pulsing stream of gases which is main reason of pipe-lines vibrations reduces piping flow rate and causes demages or wrong readings of used measuring equipment /3,4,5,6/. To decrease negative influence of excessive pressure pulsation, first it is necessary to determine the real quantity of them, and next rules of propagation pressure pulsation have to be discovered. Also the action of pressure pulsation on the piping of compressed gas must be understood. In spite, that majority of pulsation problems in many countries are actually solved by Electro-Acoustic Analogy using analog simulator it is impossible to stop investigations of these problems at installations in laboratory and industry conditions. This investigations are only one way to prove correctness of analog of considerated piping system and they are source of informations which afterwards can be used for defining accurately assumpted analog and correcting frontier conditions /2,3,6/.

MEASURING EQUIPMENT FOR RECORDING PRESSURE PULSATION

The diagrams of pressure pulsation at various points of pipe-line and indicator diagrams recorded by use of electric indicator are base for analysis of influence pressure pulsation at compressor working conditions and at compressed gas piping. Pressure pulsation diagrams recorded in front of and behind the damper are the base for estimating its damping coefficient. These diagrams are plotted as a function of angle of crankshaft rotation /φ/ or time /τ/. In substance, for pressure pulsation measuring, all types of electric indicators usually used for high speed piston machines indication can be applied as one of the methodes of quick-changeable pressure measurement. Therefore, various types of indicator can be used, such as piezoelectric, capacitive, inductive and tensometric /1,8/. Whichever electric indicator consists of three general elements i.e. pressure transducer, amplifier and recording unit. Below are discussed metrological requirements which have to be complied by mentioned indicator's elements during pressure pulsation measurement in compressor piping.

Pressure Transducer

Specificity of pressure pulsation measurement is that the pressure variable component oscilating about constant component is measured. The value of constant component equals to mean pressure in pipe /Fig. 1/. The measuring range and strength of transducer must be conformed to value of pressure p_o, while the measured value of pressure Δp_a makes only a fraction of value p_o. Accuracy of value Δp_a measurement requires a transducer of special design which contains:

- Measuring range complied to value of pressure in piping /p_o/.
- High free frequency.
- Linearity of indication all over the measuring range.
- Non-sensitivity to temperature of environment and measured medium.
- High sensitivity.
- High rigidity.
- Absence or possibly short passage between transducer input and diaphragm.
- Indication stability after long running period.
- Facility of service and reliability.
- Possibility of long distance operating

for measuring purpose.
- Possibility of static calibration.

It appears that requirements demanded from transducers used for pressure pulsation measurement are very high and even contrary sometimes. Especially difficult is to get high sensitivity contemporary with large mea-suring range.

Amplifier

In mentioned electric **indicator** usually two types of amplifiers are applied:
- Direct current amplifier which has very wide carrying band from frequency value of 0 to this value which is limited by free frequence of used transducer. Imperfection of this types is zero drift so it can not be applied for long period measurement.
- Carrying frequence amplifier which also can operate at frequence value of 0 but its upper band limit is restricted to about 1/5 of carrying frequence value. This amplifier is convenient for co-operation with passive transducers /such as tensometric/ working in bridge units.

Requirements that have to be complied for both types of amplifiers are: high amplification factor, constant amplification factor all over the carrying band and linear amplitude characteristic in working range of pressures.

Recording Unit

For recording rapidly fluctuating pressures can be applied cathode or loop oscillographs. Differences between cathode oscillographs used for above-mentioned purpose and typical cathode oscillographs lay in much more complicated sweep generator and diagram marker design. For recording only the single cycle of pressure change the trigger unit of horizontal cathode spot shift is introduced. Diagrams obtained at oscillograph's screen can be observed or photographed.

The loop oscillograph enables observing of pressure pulsation diagrams at groundglass screen and plotting of them on the recording paper. Imperfection of loop oscillographs is their relatively low free frequency, which makes possibility of not very accurate higher harmonics recording. Adwentage of thees oscillographs is that they are usually made as multi-channel recording oscillographs.

PIEZOELECTRIC INDICATOR

Piezoelectric indicator is the most convenient equipment for high frequence pressure measurement. It is produced and delivered by many of manufacturers as complete measuring unit. Considering usability of piezoelectric indicator for pressure pulse measuring purpose it is mecessarily to sum up all its faults and advantages. There are following advantages of piezoelectric indicator:
- Temperature independance of transducer indications in working temperature range.
- Compact form of transducer. Miniaturisation of piezoelectric transducer is very high in comparison to any another types of transducers. Signal from transducer can be transmited by single cable.
- Comparatively high sensitivity and high free frequency of transducer which comes from very small deformations of its active elements.

Faults of piezoelectric indicator:
- Necessity of dynamical calibration.
- Short length of cables connecting transducer with amplifier and recorder since the input capacity must be of low value.

Length of connecting cables applied in piezoelectric indicators of earlier types was up to 3 ÷ 4 meters. Therefore, their aplication had to be restricted only to particular measuring cases in laboratory conditions. In modern, developed versions there is the possibility to set amplifier and recorder at a certain distance from transducer. First amplifier stage, of high input resistance /electrometer stage/ is manufactured as the seperate sub-unit. Then, this stage is connected to transducer by short, low capacity cable and to another parts of equipment by special about 15 meters long cable. Block diagram of such indicator is shown at Fig. 2. By use of this indicator, diagrams of pressure pulsation as the functions of piston stroke /s/, crankshaft angle /φ/ or time /τ/ can be recorded. Pressure pulsation diagrams as the functions of crankshaft angle /φ/ are considered, when aim of measurement is to define influence of them on compressor working process. Now, when the measurement is carrying out only to designate the damping coefficient, diagrams of pulses are plotted as function of time /τ/. Then measuring equipment contains only thees components, which take a part in driving the c.r.t. Y plates becouse the c.r.t. X plates are driven by sweep generator sub-unit.

EXAMPLES OF MEASUREMENTS

Author has carried out the series researching works in subject of pressure pulsation influence on compressor working process, propagation of this pulsation in various pipe-line's systems and damping of them in inlet and outlet pipes. During thees investigations the measurement of pressure pulsations has been taken out by use of piezoelectric indicator assembled as it is shown at Fig. 2. Measurements have been done at various absolute pressures in piping, using for them standard transducers of following measuring ranges: -1 ÷ 5, -1 ÷ 10, 0 ÷ 60, 0 ÷ 100, 0 ÷ 150 bars.

At Fig. 3 is shown diagram of pressure pulsation existing in outlet pipe of one cylinder air compressor during resonance with first harmonic and indicator diagram due to this case. The absolute value of pressure pulsation is equal in this case to Δp_a = 1,19 bars what makes 39,7 per cent of value p_o. Pulsations effect on compressor working process appears in considerable increase of maximum pressure in cylinder and power demand for compression of medium. Maximum pressure value in cylinder reached in this particular case p_{max}= 4,80 bars, while the pressure in outlet pipe was p_o= 3 bars.

Fig. 4c shows oscillograms of pressure pulses existing in inlet pipe of two-sided action, four-stage compressor. Here, pressure value in pipe is p_o= 0,975 bars, crankshaft speed $\dot{n}$ = 300 rev/min and compressed medium CO_2. Characteristic for this case is slight damping effect of separator, which has been set up in this installation /capacity of separator V_b= 3,15 m^3/. Calculations concerning free frequence of gas mass closed in piping, that have been made for assumed equivalent acoustic system /Fig. 4b/ had shown that it is very close to resonance with impressing frequence $\dot{n}_o/2\dot{n}$ = 1,06 /Fig. 4d/.

Fig. 5 shows pressure pulsation oscillograms in front of and behind the damper, installed at outlet pipe of one-cylinder, experimental air compressor. There was applied, suggested by author resonant damper of considerable damping coefficient value. In this particular case damping coefficient is equal K_t= 4,8.

Pulse oscillograms given in Fig. 6,7 and 8 does not require much discuss. It should be added, that oscillograms shown at Fig. 7 and 8 were recorded with highest attainable amplification level of used equipment. The exemplary oscillograms given at Fig. 4 and 5 were taken out during investigations of laboratory installations, while all anothers come from industrial plants. Almost all oscillograms annexed to this paper have been photographed at high brightness of picture and they are appropriated only for information purpose. The exception is Fig. 6 which shows pressure pulsation oscillogram being the base for estimating numerical values used next in calculations. From analysis of pressure pulsation measurements accuracy it is possible to state that to assure high accuracy of measurement piezoelectric low-pressure high-sensitivity transducers must be applied. In case of existing higher pressures in pipings /over 10 bars/, so when there is the necessity of using wider measuring range transducers, the accuracy of pulsation measurement is not sufficient. Then, in order to get correct results, the special design differential transducers have to be employed.

SPECIAL DESIGN TENSOMETRIC DIFFERENTIAL TRANSDUCER OF PRESSURE

The differential transducer of special design can most comprehensively comply all requirements of proper pulsation measurement. This transducer assures high-sensitivity and due to it high measuring accuracy both at low and high pressure value. Most simple in manufacturing is tensometric differential transducer. Schematic diagram which explains its principle of action is given at Fig. 9. This transducer is connected to pipe-line with screw connector. Pressure pulsations through hole in connector are acting at diaphragm. Becouse the diaphragm should only response to pressure pulsation, it is necessery to lead into upper chamber gas, which pressure is equal to mean pressure value existing in pipe-line. For mentioned purpose the proper, pressure pulsation damper of very high damping coeficient must be employed. Differential transducer and damper are housed in common casing. To upper chamber the manometer measuring mean pressure in pipe-line can be connected. Connector can be also utilized for leading gas at certain pressure into upper chamber, what makes the possibility of easy calibration of transducer at conditions close to working conditions. As the adventages of this transducer can be noted possibility of its static calibration and its action at long distance from measuring equipment /9/. Measuring system of tensometric transducer is the same as tensometric indicator. Block-diagram of such indicator is shown at Fig. 10. There were some technical difficulties in realization of described transducer, such as realization of damper, lead-in of gas at constant pressure above the diaphragm and sealing of electric cables in housing. After all thees difficulties have been overcome, tensometric differential transducer had the perfect performance.

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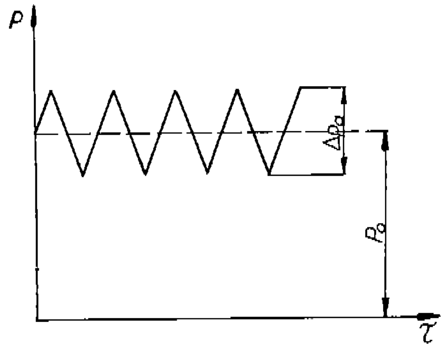


Fig. 1. Pressure pulsation in pipe-line.

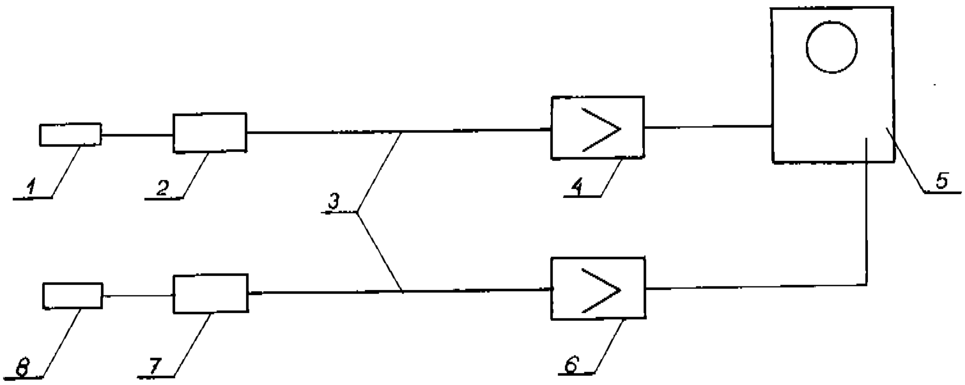
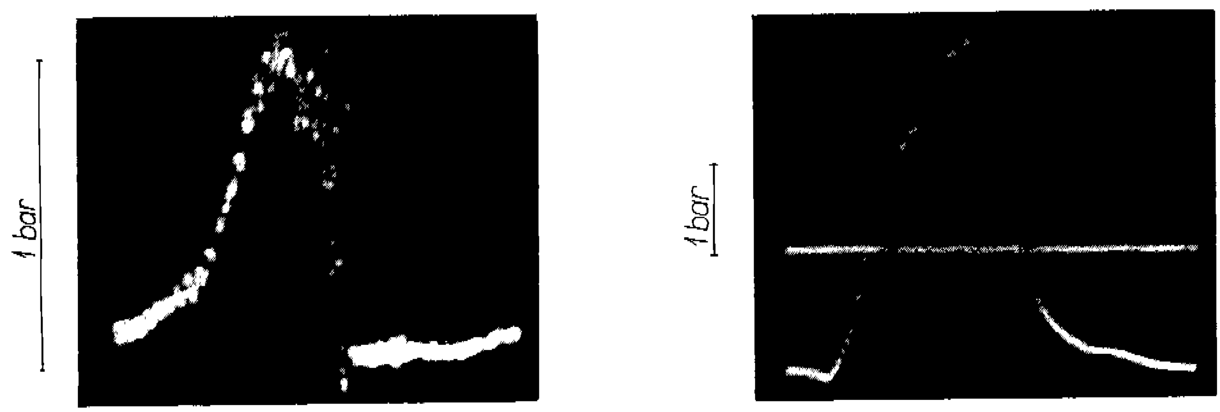
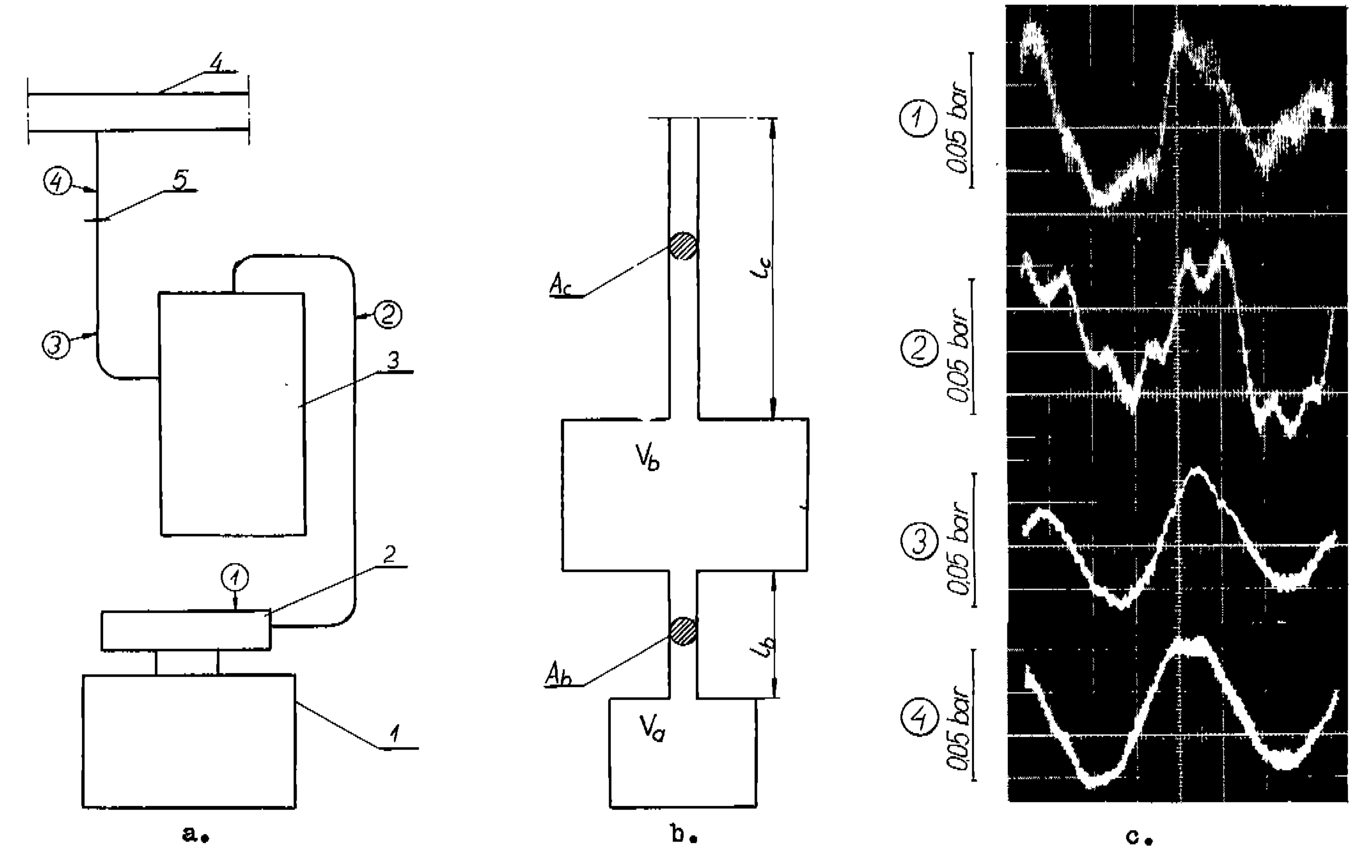


Fig. 2. Block diagram of piezoelectric indicator: 1 - transducer, 2 - electrometer stage, 3 - cables, 4 - Y - amplifier, 5 - oscillograf, 6 - X - amplifier, 7 - demodulator, 8 - piston-stroke transducer /modulator/.



a. b.

Fig. 3. Oscillogram of pressure pulsation in outlet pipe during the resonance with harmonic base /a/ and according indicator diagram /b/; p_o = 3 bars, $\dot{n}$ = 1150 rev/min, /p $-\varphi$ /.



$$\underbrace{V_b\,\frac{\omega}{a}}_{I} = \underbrace{\frac{\left(\frac{V_a\omega}{a\,A_b} + tg\,\frac{\omega\,l_b}{a}\right)A_b}{\frac{V_a\omega}{a\,A_b}\,tg\,\frac{\omega\,l_b}{a} - 1} + \frac{A_c}{tg\,\frac{\omega\,l_c}{a}}}_{II}$$

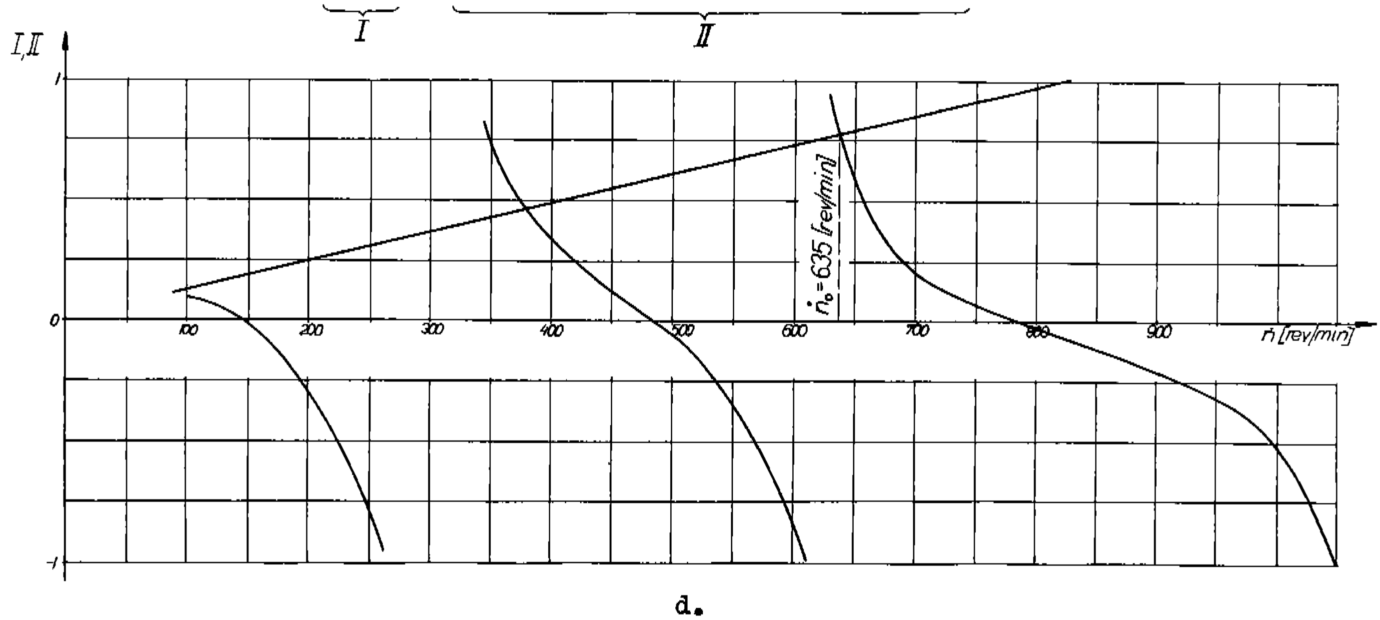


Fig. 4. Propagation of pressure pulsation inside of inlet installation; a - outline of installation, b - autline of equivalent acoustic system, c - oscillograms of pressure pulsation at certain points /p - φ/, d - graphical estimation of resonant revolutions.

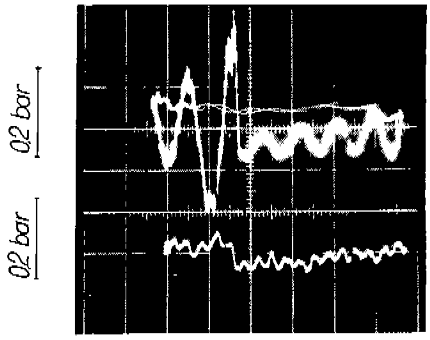


Fig. 5. Oscillograms of pressure pulsation in outlet pipe in front of and behind the resonant damper. /p $-\varphi$/; p_o= 4 bars, $\dot{n}$ = 1100 rev/min.

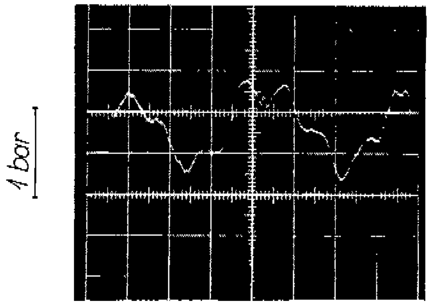


Fig. 6. Oscillogram of pressure pulsation in outlet pipe /p $-\varphi$/; p_o= 9 bars, $\dot{n}$ = 590 rev/min.

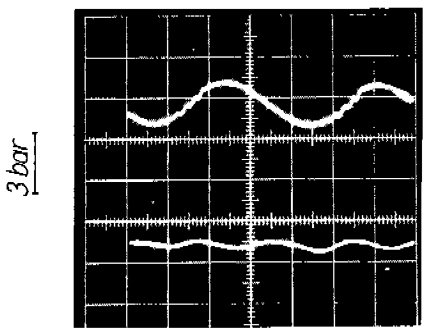


Fig. 7. Oscillograms of pressure pulsation in front of and behind the damper in inlet pipe of motocompressor /p $-\tau$/; p_o= 32,2 bars, $\dot{n}$ = 330 rev/min.

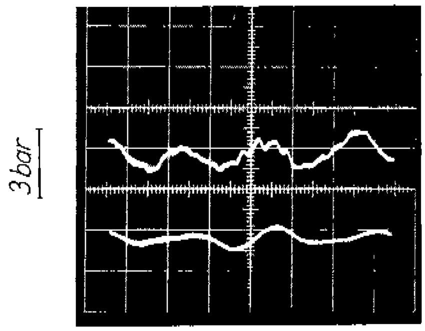


Fig. 8. Oscillograms of pressure pulsation in front of and behind the damper in outlet pipe of motocompressor /p $-\tau$/; p_o= 47,5 bars $\dot{n}$ = 330 rev/min.

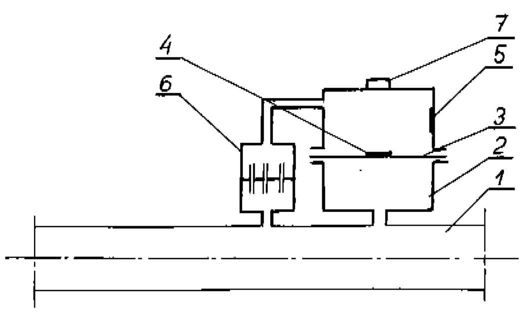


Fig. 9. Diagram of tensometric differential transducer: 1 - pipe-line, 2 - transducer, 3 - diaphragm, 4 - measuring tensometer, 5 - temperature compensating tensometer, 6 - pressure pulsation damper, 7 - pressure gauge connector.

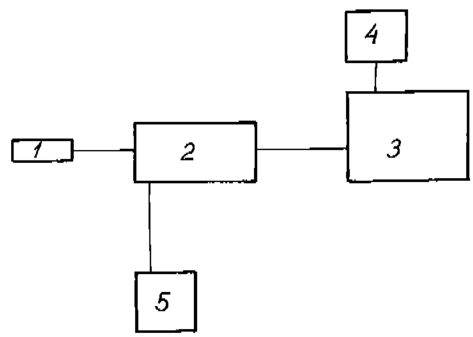


Fig. 10. Block diagram of tensometric indicator: 1 - transducer, 2 - measuring bridge with amplifier, 3 - oscillograf, 4 - time-marker, 5 - carrying frequence oscillator.

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